Determination of the Spatial Variation of the Atmosphere and Ocean Wave Fields in Extremely Light Wind Regimes

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LONG-TERM GOALS

Existing parameterizations of heat, moisture, and momentum fluxes in the marine atmospheric boundary layer (MABL) perform poorly under weak wind regimes, especially in regions of inhomogeneity. These problems are due to a variety of processes (e.g., averaging techniques, gravity capillary wave spacing, surfactants and surface tension, free convection effects, frequency-dependent differences between wind, waves, and stress). In order to address these various forcing mechanisms, high-resolution, high fidelity atmospheric and surface wave data are needed to describe energy exchange across the air-sea interface. The overall long-term goal of the Coupled Boundary Layers and Air-Sea Transfer (CBLAST) low-wind initiative is to acquire these data to better understand air-sea interaction in extremely light wind regimes.

OBJECTIVES

The objective is to advance the understanding of processes that control the exchange of heat, moisture, and momentum across the air-sea interface. To that end, we will use measurements from the LongEZ aircraft of wind, temperature, momentum, and surface wave properties to identify processes that influence fluxes of momentum and sensible and latent heat in the low-wind MABL. We will provide our findings to other CBLAST investigators who may use our data for testing flux parameterizations and boundary conditions for large eddy simulations.

APPROACH

The LongEZ (N3R) research aircraft has been used extensively to acquire data for a variety of air quality and environmental research projects. The LongEZ was instrumented with various *in situ* and

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remote sensors for the measurement of atmospheric and wave field properties. The suite of instruments centered around the "Best" Aircraft Turbulence (BAT) Probe has been used on the LongEZ and other various atmospheric research aircraft to acquire high-frequency measurements of wind, temperature, pressure, humidity, and radiation. In addition, the LongEZ utilized a laser altimeter array and Ka-band scatterometer to determine long and short wave characteristics of the sea surface.

Data collected in 2001 by the LongEZ are the centerpiece for our analysis to meet the objectives as listed above. Specifically, we are using the LongEZ turbulence data and the remotely sensed wave measurements, augmented by surface buoy data to complete analysis of turbulent fluxes and transfer coefficients and to determine linkages with sea state. Direct comparisons between estimates of MABL parameters computed from the LongEZ measurements and other techniques (*ie* buoys, SAR) are necessary to understand under what conditions one (or several) of the methods may (or may not) be accurate. To this end we are conducting an extensive comparison between buoy, SAR, and LongEZ measurements to place in context our findings for the analysis of turbulent fluxes and transfer coefficients.

WORK COMPLETED

During the summer of 2001, N3R completed 20 research missions totaling roughly 52 flight hours south of Martha's Vineyard. Our analysis focuses on these data, as no N3R data were collected during the 2002 field campaign due to the fatal stroke suffered by co-PI and pilot Timothy Crawford.

To interpret the measurements from the laser altimeter array it was necessary to develop an altitude algorithm combining the measurements from the high-speed lasers and the differentially corrected GPS. Further, detailed analysis was carried out on data from one of the days from the 01 field experiment. Turbulent fluxes and transfer coefficients were computed and compared with key atmospheric and sea state parameters for this day. Findings were presented at the AMS conference in early 2003. This study has been extended to include all days from the 01 field campaign. The data set comprise numerous days where winds were between 5 and 8 ms^{-1}, with two to three days with winds both below and above this regime.

Initial comparisons between winds computed from SAR, buoys, and LongEZ are complete. Refinements to the comparisons are underway, and a draft paper highlighting the instrumentation aspects and wind calculations from the BAT probe system is in preparation.

RESULTS

Work is ongoing with the analysis of fluxes and transfer coefficients and the comparison of aircraft results with the COARE bulk algorithm results. Two versions of the COARE algorithm have been used. When the latest version (v3) became available the Fortran code was converted to IDL and applied to the data from CBLAST 01 field campaign. This latest version includes two models that account for the sea state through either a wave age parameterization or wave slope parameterization. Work has been directed at determining the wave state parameters from the aircraft laser data. It was necessary to write code based on the algorithm presented by Sun *et al.* (2003). In this paper (currently under review) Sun *et al.* demonstrate the capability to determine the true wave number and the wave propagation speed and direction based on data from the laser array. Sun *et al.* present the theoretical basis and data from the LongEZ in SHOWEX demonstrating the capability. Figure 1 shows an FFT from one of the lasers for data taken from two opposing flight directions on 25 July. The primary wave number is easily discerned from the peak in the spectra. The change in the location of the peak is due to the Doppler shift in the encountered frequency between two opposite headings. The wave propagation direction will be determined by comparing the phase at the peak frequency for all three lasers in the array.

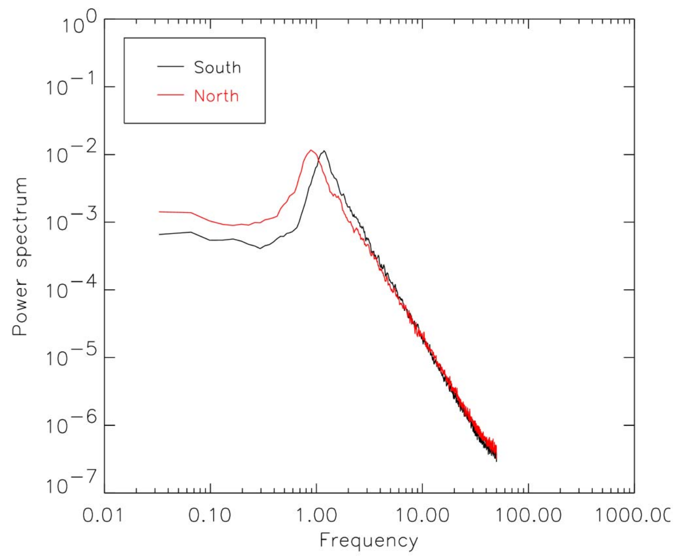

Figure 1: Power Spectra for Laser Altimeter for two legs (North and South) illustrating the encountered frequency for the dominant wavelength (~1 Hz, corresponding to 50 m).

Figure 2 shows comparisons between neutral drag coefficient ($C_{D\text{-}10N}$), z_0, u* computed rigorously using LongEZ high-frequency (HF) data and the COARE algorithm (v3) with inputs taken from 60 second averaged LongEZ measurements. These data comprise all flights in the CBLAST 01 field campaign. The results are averaged based on 0.5 ms^{-1} wind speed bins. For wind speeds up to roughly 8 ms^{-1}, there is in general good agreement between the COARE algorithm and the aircraft HF measurements/calculations. Above 8 ms^{-1}, the aircraft HF measurements are significantly less than the COARE. This regime is based on three days of data, one of which shows reasonable agreement. For the comparison between drag coefficient, there exists similar behavior for winds above 8 ms^{-1}. Also for moderate-light winds (4-6 ms^{-1}), the aircraft HF measurements are less than the COARE. For our present research we are investigating whether differences in sea state may account for these differences.

Figure 3 shows comparisons for latent heat flux (H_l) and sensible heat flux (H_s) for all of the flights from the 01 field campaign. In general, comparison is good between the aircraft calculated values and that computed using the COARE algorithm. The aircraft calculations are less than the COARE values for latent heat flux at low values (possibly a sensor issue with the IRGA) and are greater than the COARE for sensible heat flux at high values. We expect the calculations of sensible heat flux from the aircraft to be likely overestimated due to the temperature sensor. A second sensor utilizing a thermocouple and designed to respond much faster than the standard BAT fast response thermistor bead was also flown in CBLAST. This new sensor does not suffer from high frequency noise contamination due to vibration and stress of the element. Data from this sensor are being processed for use in further analyses.

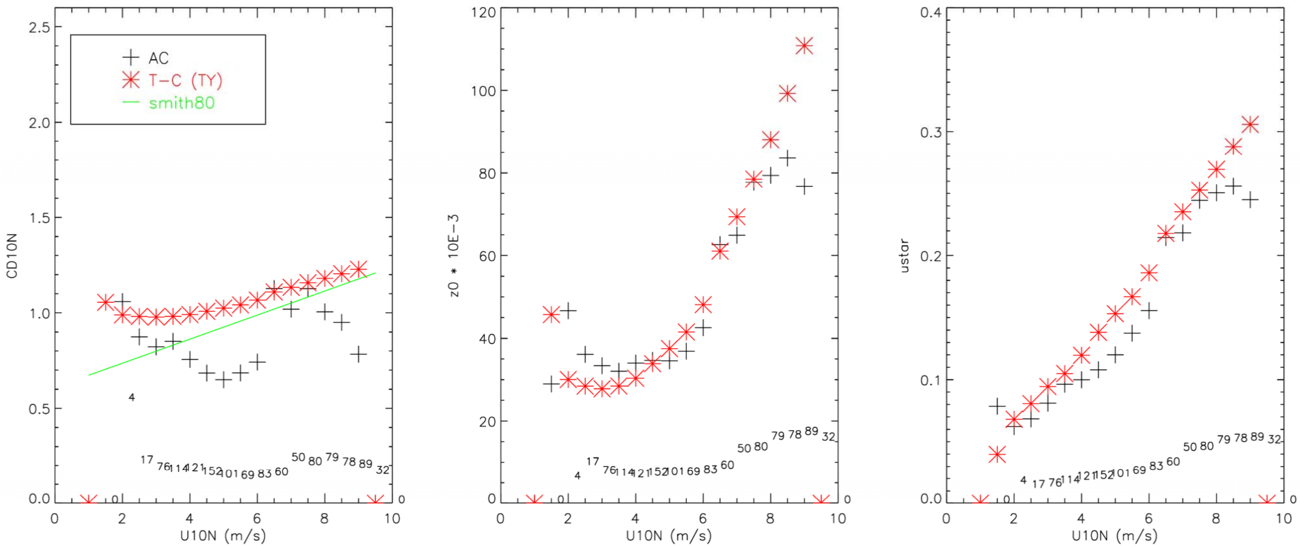

Figure 2: Drag Coefficient ($C_{D\text{-}10N}$), Z_0, and U* as a function of 10 meter-neutral wind speed for the LongEZ high frequency data and calculated from the COARE algorithm (LongEZ 60 second averages) for all days in CBLAST 01 field campaign. Data are averaged over 0.5 ms^{-1} bins; numbers at bottom represent number of data points in each bin.

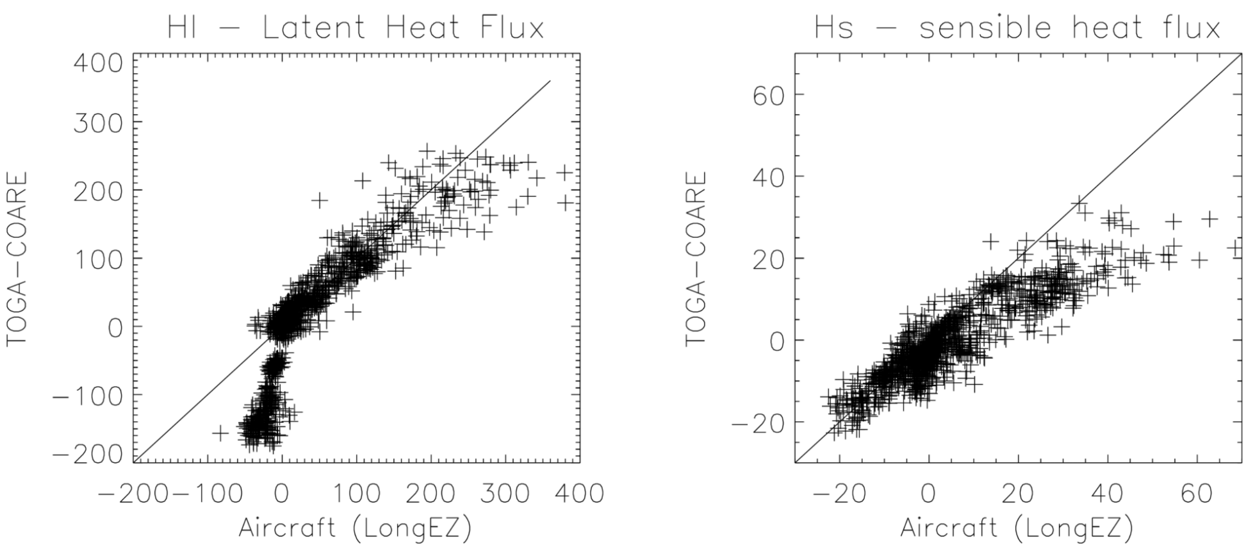

Figure 3: Latent Heat Flux and Sensible Heat Flux calculated from the LongEZ HF data and the COARE Algorithm for all of the days in CBLAST 01 field campaign.

IMPACT/APPLICATIONS

The data acquired by N3R and our continued analysis of these data will have a direct impact on our understanding of energy exchange processes across the air-sea interface in the light-wind MABL. Until now, very little turbulent flux data existed for a light-wind MABL. N3R has simultaneously acquired atmospheric turbulence and ocean surface data under a variety of stability regimes in a light-wind MABL. These data will be used to improve parameterizations describing air-sea transfer processes.

TRANSITIONS

N3R data will be used and is being used by other CBLAST-Low investigators for surface-based and satellite-based inter comparisons. These data will support the testing and refinement of parameterizations used in air-sea models. In addition, such measurements provide important boundary conditions to determine boundary layer turbulence and other atmospheric processes controlling the exchange of energy across the air-sea interface.

RELATED PROJECTS

Data that were acquired during the Wave Profiling Experiment (WAPEX) and the Shoaling Wave Experiment (SHOWEX) are being used to augment the data from CBLAST-Low. Insight into the CBLAST data is gained through the continued analysis of these earlier data sets.

A BAT probe is being used on one of the NOAA P3's to acquire flux measurements within hurricane boundary layers in support of the CBLAST-Hurricane effort. Although these data are at the other end of the spectrum in regards to scale, they do provide valuable insight for the interpretation of the LongEZ measurements. And conversely, the experience gained from the LongEZ in WAPEX, SHOWEX, and CLBAST-Light is valuable for the CLBAST-Hurricane effort.

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HONORS/AWARDS/PRIZES

Dr. Timothy Crawford, one of the original Co-Pis for this effort, was awarded the Department of Commerce Gold Medal (Posthumously). He was cited for "pioneering scientific and engineering contributions to the Department through untiring and extensive personal efforts in establishing and advancing the small environmental research aircraft (SERA) concept for the study of airborne geosciences worldwide." Much of Dr. Crawford's effort came as a direct result of not only his effort in CBLAST but previous ONR support of his and his team's effort in earlier experiments investigating air-sea interaction including SHOWEX.